AMTC
Low Cost Manufacturing of Composite Cryotanks
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Objectives

• Develop and Validate Manufacturing Processes and Technology for Fabrication of Large Scale Cryogenic Tanks
• Establish Scale-Up and Facilitation Plan for Full Scale Cryotanks
• Develop Non-Autoclave Composite Manufacturing Processes
• Fabricate Subscale Tank Joints for Element Tests
• Perform Manufacturing Risk Reduction Trials for Subscale Tank
• Develop Full Scale Tank Manufacturing Concepts
Non-Autoclave Evaluation Factors

- Compatibility With Design
- Ability to be Scaled Up
- Maturity of Materials
- Laminate Quality (Compared to Autoclave Baseline)
  - Cure Laminate Thickness / Thickness Variations
  - Defects and Other Anomalies (Laminate Porosity, Blending / Resin Starved Conditions, Unsealed Edges, Encapsulating Air and Voids)
  - Laminate Anomalies (Black-off From Processing, Fiber Waviness / Waveless Fiber Volume / Resin Volume Variations)
  - C-scan
- Mechanical Properties

VARTM Evaluation

Materials Maturity
- Unidirectional Preforms Need Significant Development
  - Uni-Fabrics Only Used in Experimental Environments and Have Minimal Process and Mechanical Data Available
  - Filament Wound Tow Preform Concept Requires Development of Compatible Sizing and Method for Integration of Doubles
- Structural Foam Cores Not Mature; Do Not Have Equivalent Strength Density Ratio to Honeycomb
- Need Develop Weight Effective Method for Sealing Bonding to use Honeycomb
- Mechanical Data on VARTM Roval Systems Was Very Limited Except for BMI Materials
  - Typically Had Lower Mechanical Properties and Toughness Than Prepreg Materials
  - Will Require Extensive Certification
Enhance Cure Processing Approaches

Mandrel Expansion
- Internal Alignment Chutes
- External Alignment Chutes
- Standard & Custom Chute Types

Spray Topper/Modifiers
- 1K & 2K Tape Spools
- Use of Primer
- Use of ACF (Adhesive Coating Finishes)

Battening Techniques
- Improved Battening
- Improved Insulation
- Improved Temperature

Specialty Materials
- Use of Special Finishes
- Use of Special Adhesives

VARTM Evaluation

Compatibility with Design
- May be suitable for Membrane Structure Concepts and for Spun Bumpers
- Use of Fillers for Full Surface Will Impose <10% or Higher Weight Penalty
- Significant Weight/Quality Risk, Particularly to Prevent Resin Impregnation for Honeycomb Sandwich Design
- Limited Flexibility in Designs Highly Restricted to VARTM Process Limitations (e.g., Perform Geometry Limitations, Injection Process, 

Enhanced Processing Techniques

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Enhance Cure Processing Evaluation

Materials Maturity
- Low Pressure Processing Materials (e.g., LTM) did not have acceptable mechanical properties or had unacceptable out times.
- Net Thickness Prepreg materials have only been used for autoclave curing.
- Standard Prepeg materials selected for most process testing.
  - Will compare to mechanical test data for autoclave cured materials.
  - Minimal mechanical data available for vacuum bag cure.

Design Compatibility
- Shrink Tape Approach Limited by Contour
  - Must be made tool with convex surface.
  - Difficult to apply to dome compound contour areas.
  - Difficult to incorporate localized features without causing bridging.
- Mandrel Expansion
  - Aids IMI skin compaction. But questionable for doubler features not constrained by skin pieces and processes after skin cured.
  - Tooling complexity increases for outer skin compaction.
  - Must rely on other complementary processes.
- Expansion approach limits tool design flexibility.
- Bagging Techniques and Specialty Materials appear compatible with most designs proposed.

Enhance Cure Processing Evaluation

Scalability
- Materials must have compatible out-life with proposed process approaches.
- Shrink Tape
  - Application process on full scale tanks may need development of automation due to weight of rolls.
- Improved Debubking
  - Need to ensure scale-up does not exceed material out-life due to increased process flow time.
- Recommend automated material application for all concepts proposed.
  - Aids debubking.
  - Reduces flow time and improves ability to complete process within out-life of materials.

Non Autoclave Cure Photomicrographs

All materials vacuum bag cure panels had unacceptable disbonds or porosity.

Materials panel 1
- Standard layup vacuum bag pressure only mat 1 a panel # 2.
Non Autoclave Cure Photomicrographs

First Mat B Panel Produced with the New Process (Panel #8)

Second Mat B Panel Produced with the New Process (Panel #10)

Non Autoclave Cure Photomicrographs

First Mat C Panel Produced with the New Process (Panel #7)

Second Mat C Panel Produced with the New Process (Panel #9)

Non Autoclave Cure Photomicrographs

Comparable Results From Panels Made for M&P Testing
Enhance Cure Panel Processing Summary

<table>
<thead>
<tr>
<th>Panel</th>
<th>Material</th>
<th>Process</th>
<th>Cure</th>
<th>Thickness</th>
<th>Visual Quality</th>
<th>Comments</th>
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<tr>
<td>1</td>
<td>A</td>
<td>Baseline</td>
<td>Baseline</td>
<td>N/A</td>
<td>Very Poor</td>
<td>Degraded Ply</td>
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<td>Baseline</td>
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<td>Degraded Ply</td>
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<tr>
<td>2</td>
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<td>Baseline</td>
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<td>Surface Porosity</td>
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<tr>
<td>3</td>
<td>A</td>
<td>New 2</td>
<td>New 2</td>
<td>N/A</td>
<td>Poor</td>
<td>Very Poor</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>New 2</td>
<td>New 2</td>
<td>N/A</td>
<td>Poor</td>
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<tr>
<td>5</td>
<td>A</td>
<td>New 3</td>
<td>New 3</td>
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<td>Very Poor</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>Baseline</td>
<td>Baseline</td>
<td>0.068</td>
<td>Fair</td>
<td>Surface Porosity</td>
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<tr>
<td>7</td>
<td>C</td>
<td>New</td>
<td>New</td>
<td>0.069</td>
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<td>8</td>
<td>A</td>
<td>New</td>
<td>New</td>
<td>0.06</td>
<td>Very Good</td>
<td>Good Panel</td>
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<tr>
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<td>C</td>
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<td>Very Poor</td>
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<td>10</td>
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<td>Good Panel</td>
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<tr>
<td>11</td>
<td>A</td>
<td>New</td>
<td>New</td>
<td>Core Panel</td>
<td>Very Good</td>
<td>Good Panel</td>
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</tbody>
</table>

Ultrasonic Compaction With Vacuum Bag Cure
Collaborative Effort Between Northrop Grumman and Foster Miller
(Utilizes Foster Miller Patented Technology)

Ultrasonic Compaction Evaluation
Materials Maturity
- Materials selected are production proven prepreg materials
- Ultrasonic compaction properties did not degrade laminate quality when used with autoclave cure on other programs
- Minimal properties available for non-autoclave UTL processing; equivalency testing required to compare to autoclave properties
- Not previously demonstrated to core

Ultrasonic Compaction Evaluation
Scale Up
- Requires automation
  - Should be integrated with automated tow or tape lamination equipment for large cryotank structures
  - Needs evaluation/development to determine if lamination and compaction should be performed simultaneously or independent of each other for optimal lamination speeds
- Development underway to scale to larger width compaction heads
- Needs demonstration on compound geometry with wider width heads
- May require special horn configurations for complex details such as hats

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Ultrasonic Compaction Evaluation

- Design Compatibility
- Compatible with all designs that could be tow/tape placed
- More difficult to support complex details like hats
- Solid state cure process needs validation for each material system
  - Not compatible with all composite materials
  - May pose challenge with some adhesive/material combinations to get proper adhesive flow

Ultrasonic Compaction of Laminates

- Initial H/C Panels
- Free standing solid state cure (SSC)
- No UTL induced pillowing
- Good adhesive fillets
- Laminate quality will improve with vacuum
- Future trials expected to improve quality of SSC over core

Ultrasonic Compaction Photomicrographs

- UTL vacuum bag/oven cure
- WR1123A LH2 panel Mat 1A
- UTL shows significant compaction improvement compared to conventional vacuum bag cure with Mat 1A
- Anticipates quality of autoclave cure

Ultrasonic Compaction Photomicrographs

- UTL with vacuum bag cure and solid state cure
- Near autoclave compaction quality with Mat 1B, needs further development for thicker laminates and other resin systems
- Conventional autoclave cure with solid state cure
- AS91571 LOX panel Mat 1B
**Mechanical Test Panel Fabrication**

- UTL Processed and Standard Oven Cure (Material B)
  - Average Per Ply Thickness: 0.0031 in / 0.0032 in
- UTL Processed and Solid State Oven Cure (Material B)
  - Excellent Quality
  - Limited Flow
  - 0.0025 in Average Per Ply
- C-scans performed at West Penn NDT, Inc

**Sample of UTL Processing Parameters**

**Non-Autoclave Process Candidates**

**Qualitative Comparison**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Ultrasonic Compaction</th>
<th>Enhanced Thermal Processing</th>
<th>VARTM</th>
</tr>
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<tbody>
<tr>
<td>Conformity With Design</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Ability To Be Scaled-Up</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Variety of Materials</td>
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<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Laminate Quality</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

**Mechanical Property Test Results**

Open Hole Tension Strain
Mechanical Property Test Results

Filled Hole Compression Strain

Double Shear Bearing Strength

Non-Autoclave Process Scale-Up

Processing Scale-up

Non-Autoclave Process Scale-Up

**Issue**
- 2nd Gen RLV Cryotank Sizes Up to 27.5 Feet Diameter and 83 Feet Long*
- Current National Autoclave Capability is Limited to 25\^\text{th} Diameter (22\' Maximum Tank OML)
- Segmented Tanks Require Joints That Pose Leakage Issues and Significantly Increase Complexity of Design, Manufacturing, and Maintenance

**Approach**
- Scale Up Existing Non-Autoclave Processes for Cryotank Manufacturing Operations

*Saturn V = 31' Diam, ET = 27'
Gantry Machine Modifications

- NGC Gantry Being Modified
- Foster Miller Ultrasonic Head Installed
- Capital Asset PO for AIM in Process
- Gantry/Ultrasonic Head Integration Completed by End of Basic Period
- Equipment to Be Used for Panel and Tubing Element Fabrication in Option 1
- 6th Axis Foster Miller Development Ultrasonic Head
- Mounting Ultrasonic Head on Gantry
- SCW Generated for AIM
- AIM 6th Axis with Head Interface Plate
- Integrate UTL Control Functions
- Install and Route Cabling, Power, and Pneumatic Systems for Head

Effect of Debuckling Pass Width and Horn Traverse Rate on Debuck Time

- Graph showing the relationship between pass width, horn traverse rate, and debuck time.
Subscale Tank Manufacturing

**Issue**
- All Up Tank Test Including LH2 Pressure Cycling and Axial Loads Required Before Option II to Achieve TRL of 6 by 2005
- Non-Autoclave Processing Development Schedule May Not Support Option I Tank Fabrication

**Approach**
- Fabricate and Test Autoclave Cured Subscale Tank in Option I to Validate Structural Design and Cryogenic Performance
- Make Subscale Tank Details Representative of Full Scale Designs to the Maximum Extent Possible

Subscale Tank Tooling Status

- R3614167105 Skirt Skin Cure Fixture
- R3614167107 Skirt Skin Bond Fixture
- R3614167111 Assembly Bond Fixture
Subscale Tank Risk Mitigation Activities

- Perform Tooling Coordination and Interface Check with Existing NASA Tools (Designs In Work)
- Evaluating Protocol Established for Working On Site At NASA
- Coordinating NGC Support and Personnel Required to Work On Site At NASA Mfg Eng., Technicians, Quality, and Engineering Manufacturing Process Risk Reduction Activities Started
- Overall Procedures / Work Process Dry Runs Started Using Process and Tool Proof Articles Prior to Fabrication of Subscale Tank in Option 1

2\textsuperscript{nd} Test Without Wrinkles

Subscale Tank Development Activities

- Subscale Tank Wall with Core
- Placing Tank O/L Skins

Belly Band Producibility Panel

- Bonded Splice fixing
- Finished Test Specimens (Top, Bottom Views)
- Bond Flaps Required Skin
- Core-Covered
- Fasiged Edges Gap

Y-Joint Test Specimen Fabrication

- Core Bonding
- Splice Overlapping
- Fabricated Specimen
- Final Specimen
- C-clamp HD
- Splice Test Jig
Summary of Accomplishments

Manufacturing

• Non-Autoclave Process Trials Complete
• Head Fabrication and Gantry Modifications 100% Complete
• Subscale Tank Test Element Fabrication Complete
• Subscale Tank Composite Splice Plates Complete
• Subscale Tank Tools 100% Complete
• Subscale Tank Risk Mitigation Demo Complete
• Full Scale Tank Simulation Models Complete
• Conceptual Seamless Tank Tool Designs Complete